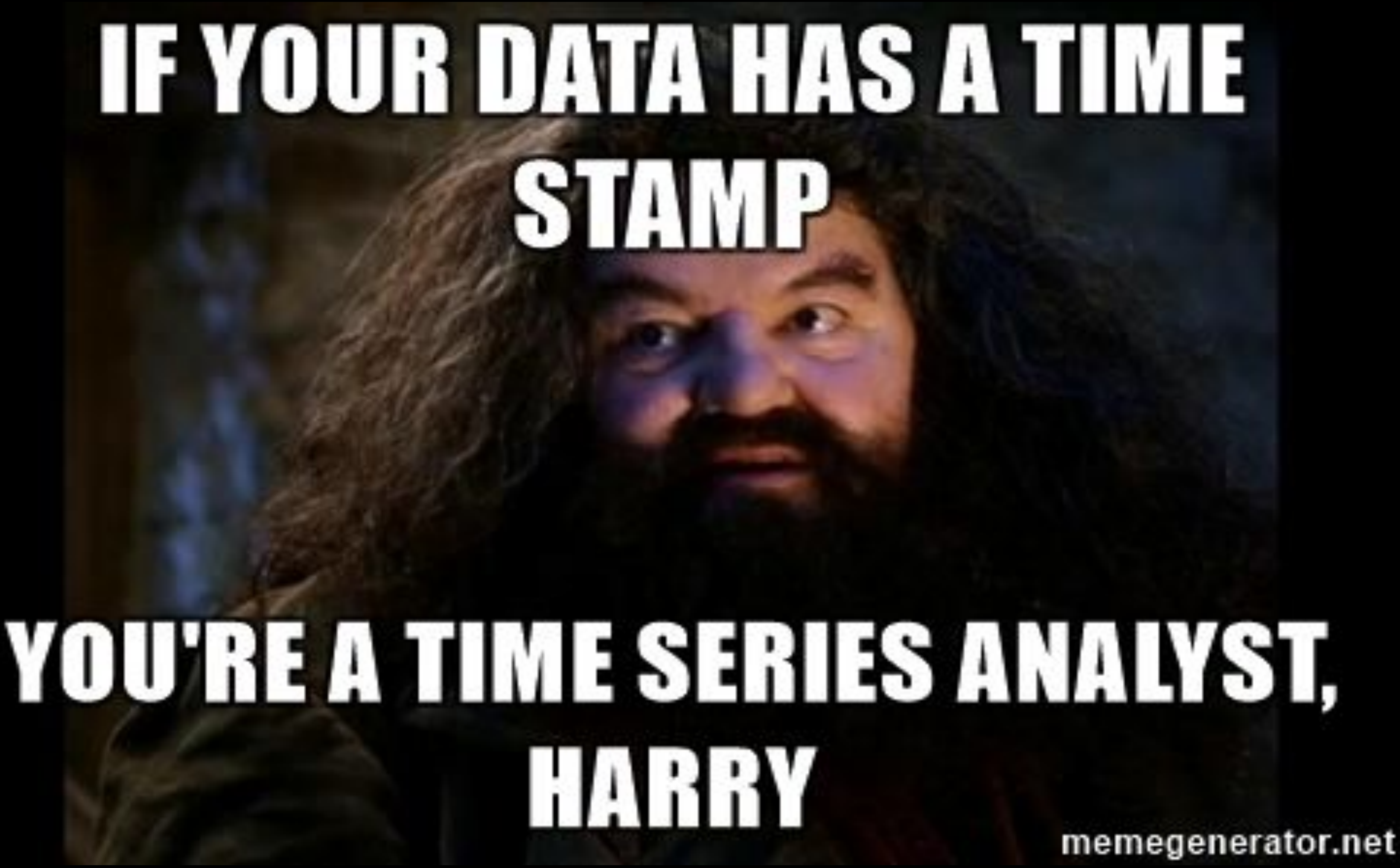
Mining Time Series

Mining Massive Datasets

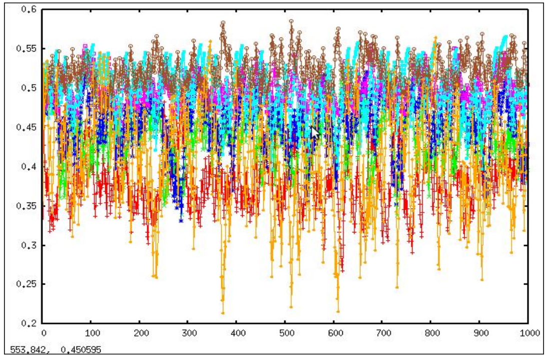
Materials provided by Prof. Carlos Castillo — https://chato.cl/teach

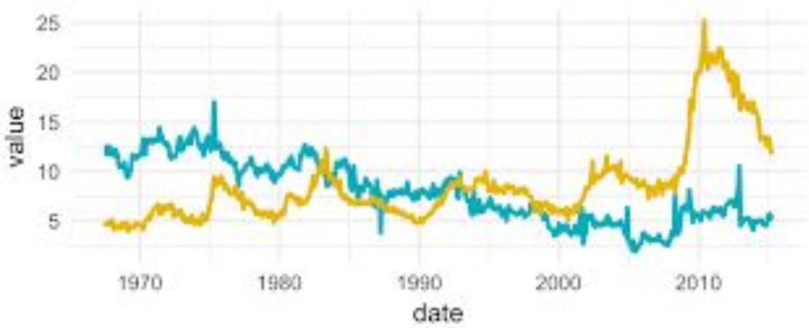
Instructor: Dr. Teodora Sandra Buda — https://tbuda.github.io/

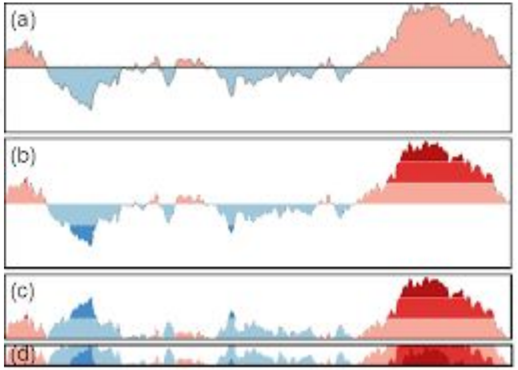

IF YOUR DATA HAS A TIME STAMP
YOU'RE A TIME SERIES ANALYST, HARRY
memegenerator.net

Sources

- Data Mining, The Textbook (2015) by Charu Aggarwal (chapter 14)
- Introduction to Time Series Mining (2006) tutorial by Keogh Eamonn [alt. link]
- Time Series Data Mining (2006) slides by Hung Son Nguyen

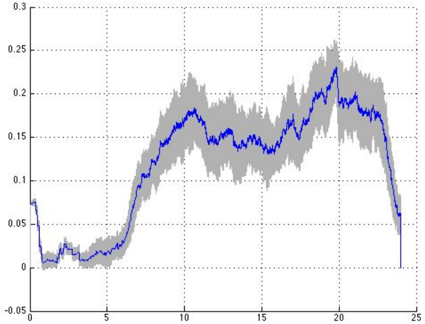


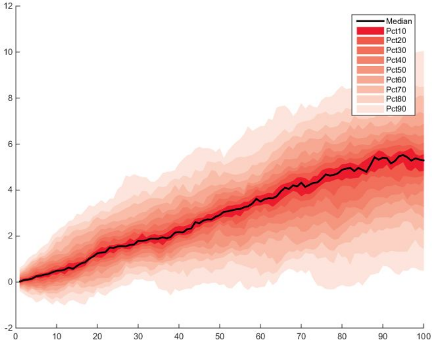


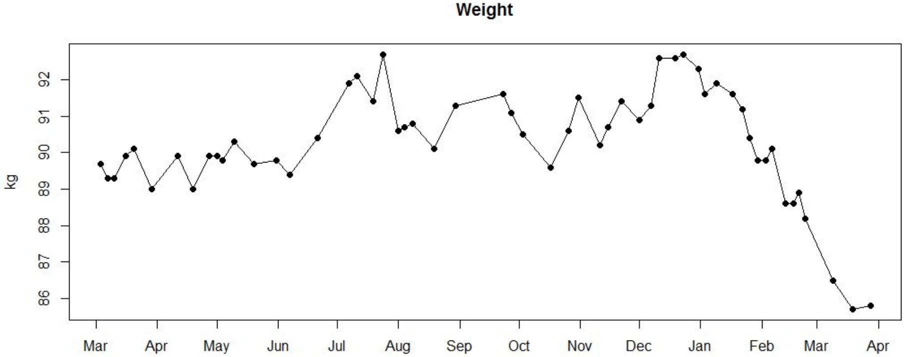


Why do we mine time series? Examples

stock prediction is a common use-case

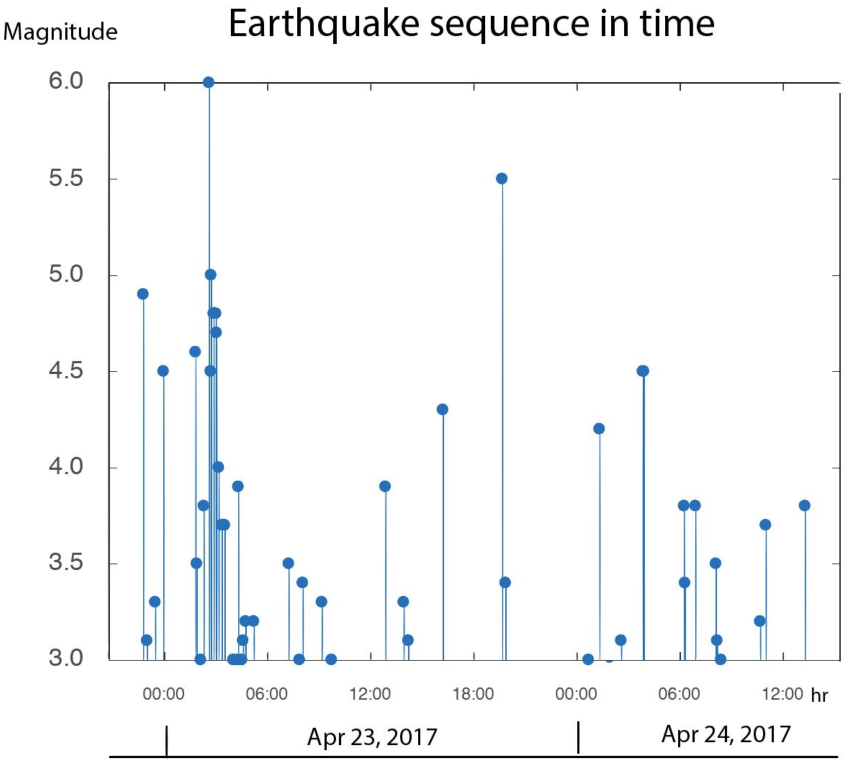


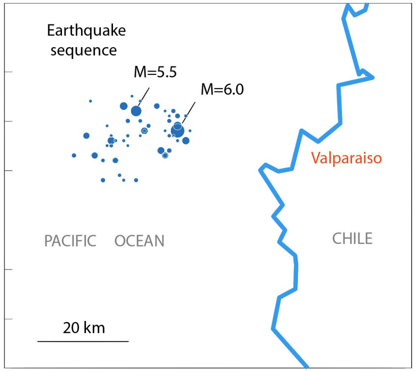




Seismic data

- Observations = earthquakes
- Goal: characterize when peaks occur



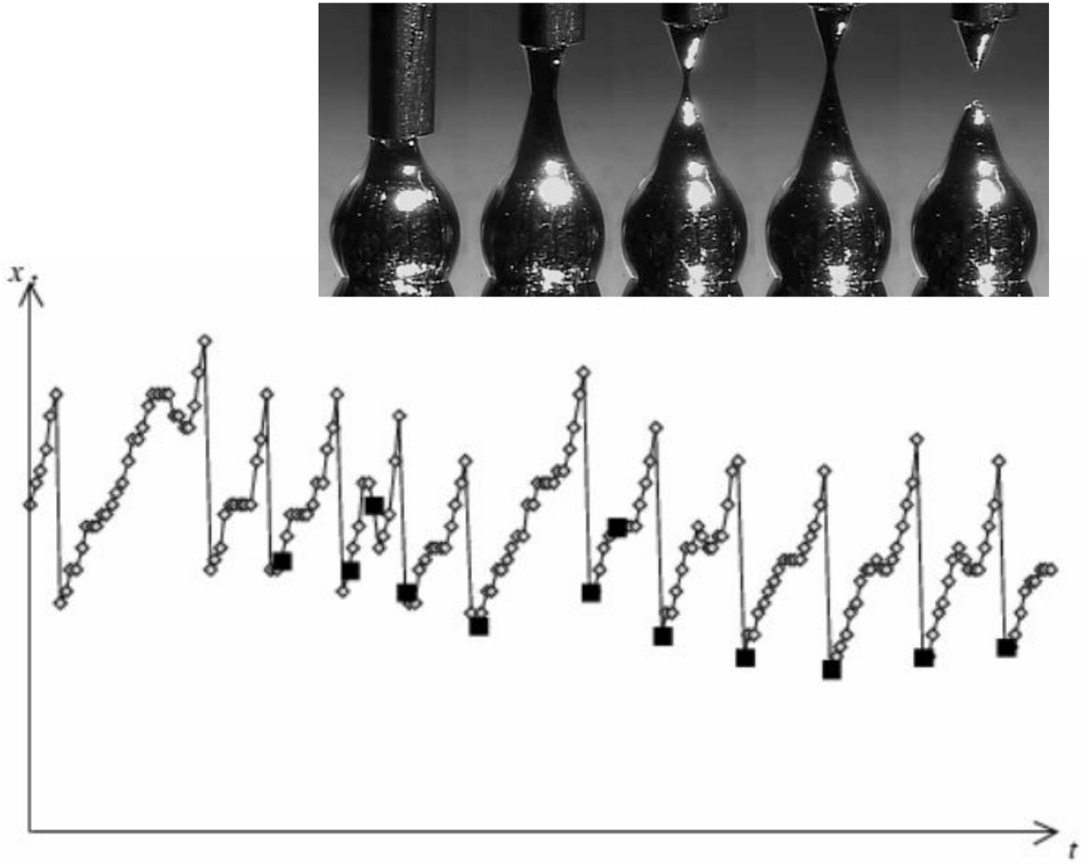


Liquid metal droplets

◇ = length of hot metal droplet

■ = droplet release
  - (chaotic, noisy)

Goal: prediction of release

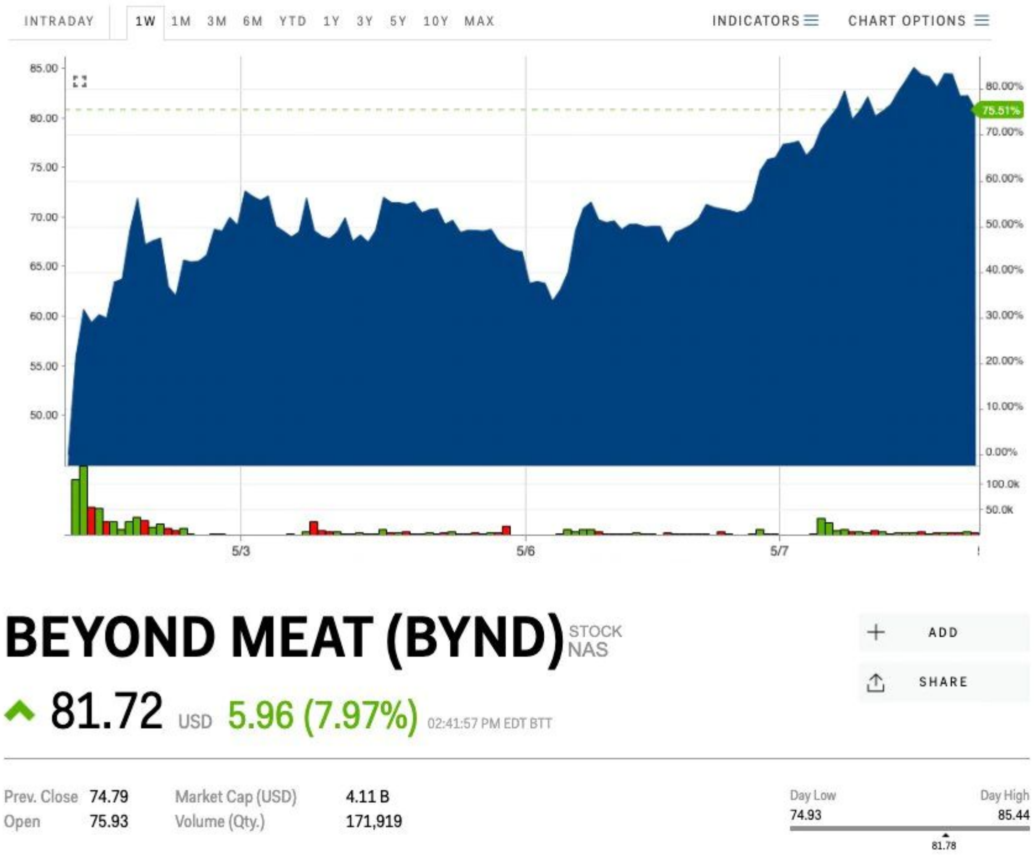


Time Series Data Mining (2006) slides by Hung Son Nguyen

Stock prices

Price

Volume traded



BEYOND MEAT (BYND) STOCK NAS

81.72 USD 5.96 (7.97%) 02:41:57 PM EDT BTT

Prev. Close	74.79	Market Cap (USD)	4.11 B
Open	75.93	Volume (Qty.)	171,919

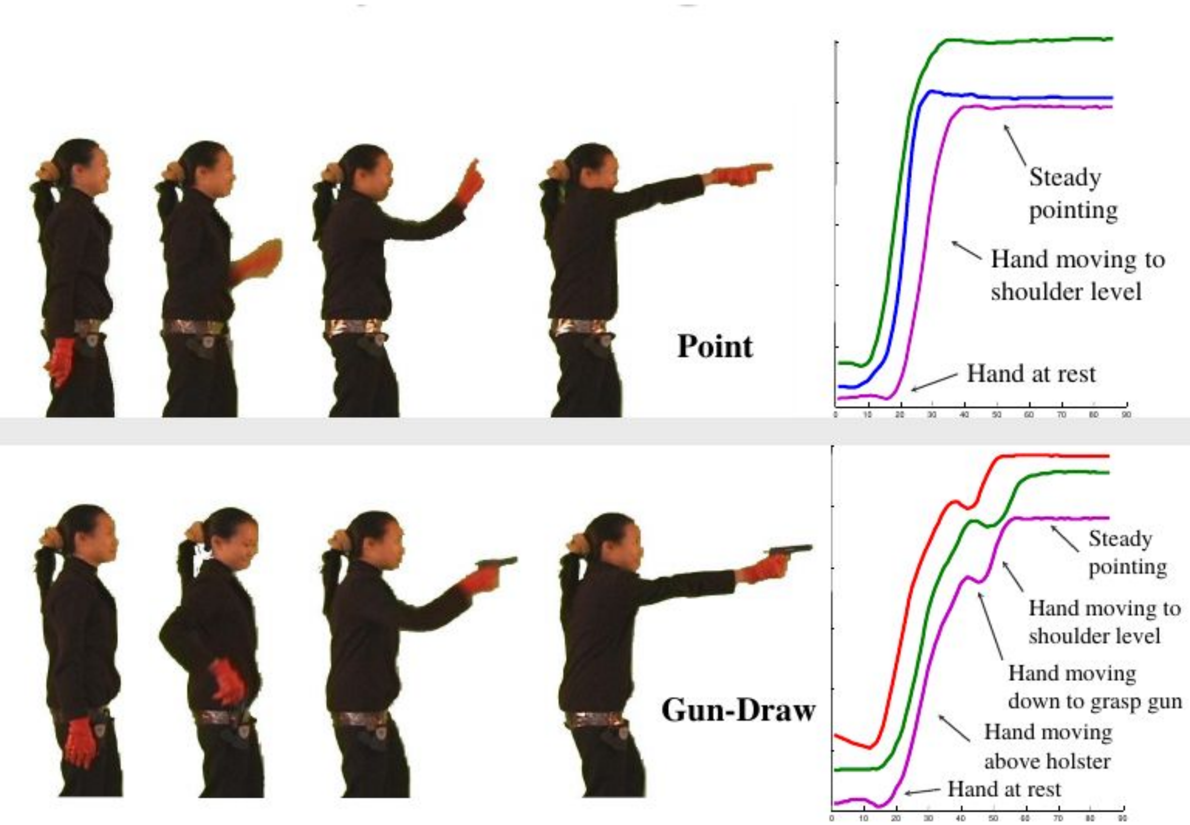
Day Low 74.93 Day High 85.44

81.78

Goal: find hidden patterns providing an advantage

Video data / gestures

- Series of angles of articulations in the body
- Temporal patterns can reveal gestures



Introduction to Time Series Mining (2006) tutorial by Keogh Eamonn [alt. link]

Applications

- Clustering
- Classification
- Motif discovery
- Event detection
- ...

1. All require a reasonable definition of the **similarity** between two time series
2. All can be done in **real-time** or **retrospectively**

Context vs Behavior

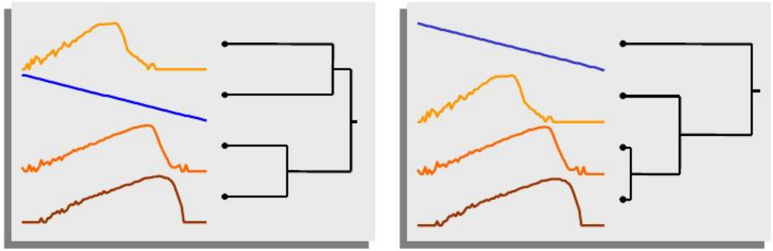
- **Contextual attribute(s)**
  - $x(i) = t_i$ = timestamp is the typical one
  - Sometimes other attributes providing context
- **Behavioral attribute(s)**

  what we are monitoring

  - $y^j(i)$ = temperature, angle, price, sensor reading, …
  - $j \in 1 \ldots d$

What are the difficulties?

- High sampling rate of many series over extended periods of time means ...
  - Tons of data
  - Things are bound to fail at several points (missing data, noisy data)
- Subjectivity



Introduction to Time Series Mining (2006) tutorial by Keogh Eamonn [alt. link]

Preparing a time series

Notation: multivariate time series

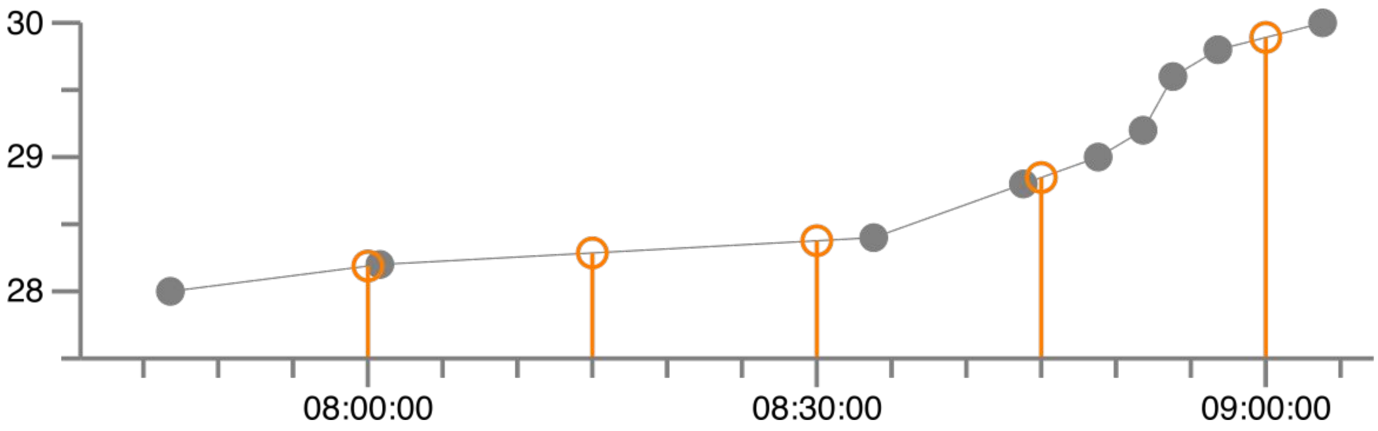
- Length n, timestamps $t_1, t_2, \ldots, t_n$
- Values at time t_i : $(y_i^1, y_i^2, \ldots, y_i^d)$
- If series is univariate we drop the superscript

Missing values: linear interpolation

- Let $t_i < t_x < t_j$

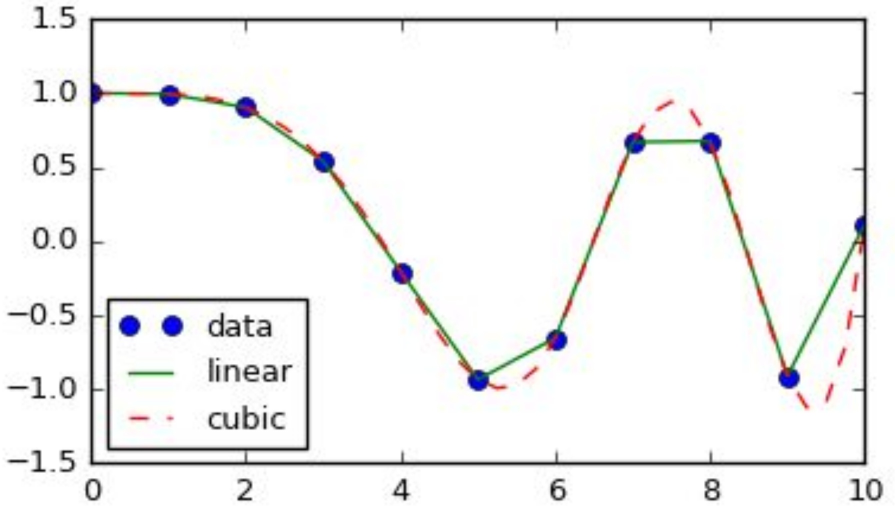
$$y_x = y_i + \left(\frac{t_x - t_i}{t_j - t_i}\right) \cdot (y_j - y_i)$$

- Example: make an irregular series regular



Missing values: splines

Cubic polynomials between y_i, y_{i+1} that have the same slope at those points as the original curve.



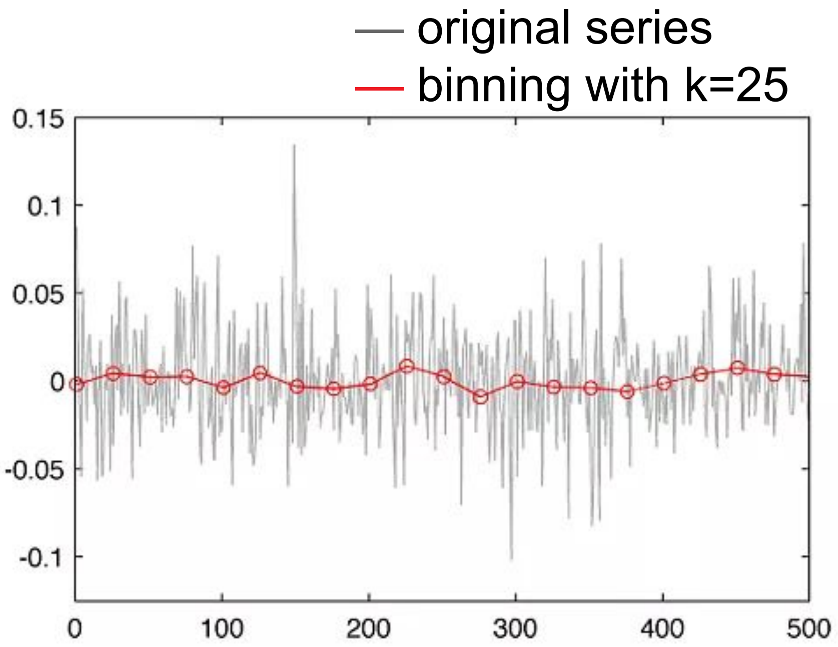
options to fill in missing values

SciPy interpolation example

Noise removal: binning

- Replace series by average of values in bins (subsequences) of length k

$$y'_{i+1} = \frac{1}{k}\sum_{r=1}^{k} y_{i\cdot k+r}$$



http://www.quantatrisk.com/2013/03/22/rebinning-of-financial-time-series/

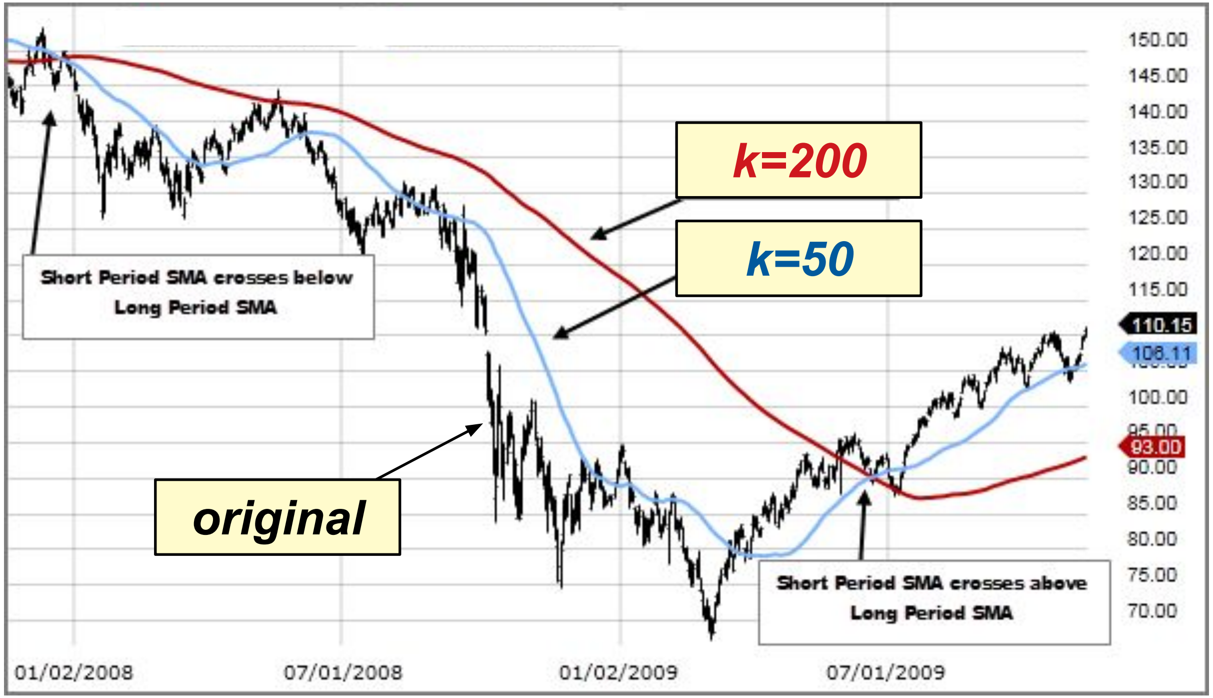
Noise removal:
moving average smoothing

- Equivalent to overlapping bins

$$y'_i = \frac{1}{k}\sum_{r=1}^{k} y_{i-r+1}$$

- Larger k leads to smoother series, but losses more information
- Use smaller k for first k-1 items

think of a sliding window that acts as a moving average



https://www.fidelity.com/learning-center/trading-investing/technical-analysis/technical-indicator-guide/sma

Noise removal: exponential smoothing

alpha is the weight of the point and 1-alpha the weight of the previous point -> tells how smooth data is going to be

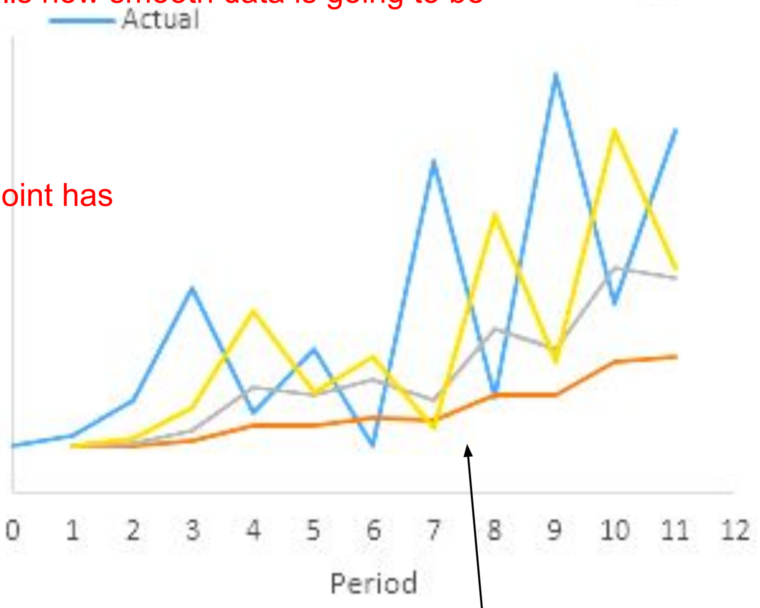
- Combine previously smoothed point with current point

if alpha is large current point has weight and otherwise.

$$y'_i = \alpha \cdot y_i + (1-\alpha) \cdot y'_{i-1}$$

- Recursively substituting

$$y'_i = (1-\alpha)^i \cdot y'_0 + \alpha \sum_{j=1}^{i} y_j \cdot (1-\alpha)^{i-j}$$



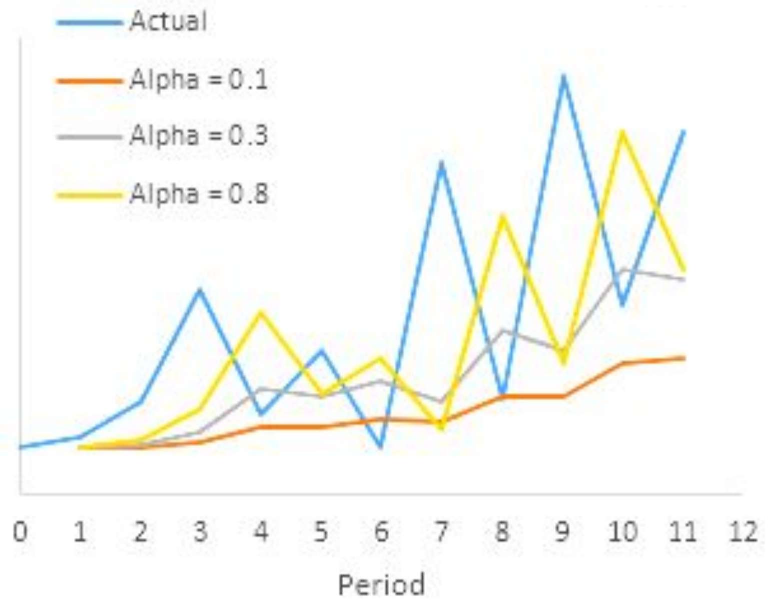
Which y' has the larger alpha?

Noise removal: exponential smoothing

- Combine previously smoothed point with
  current point

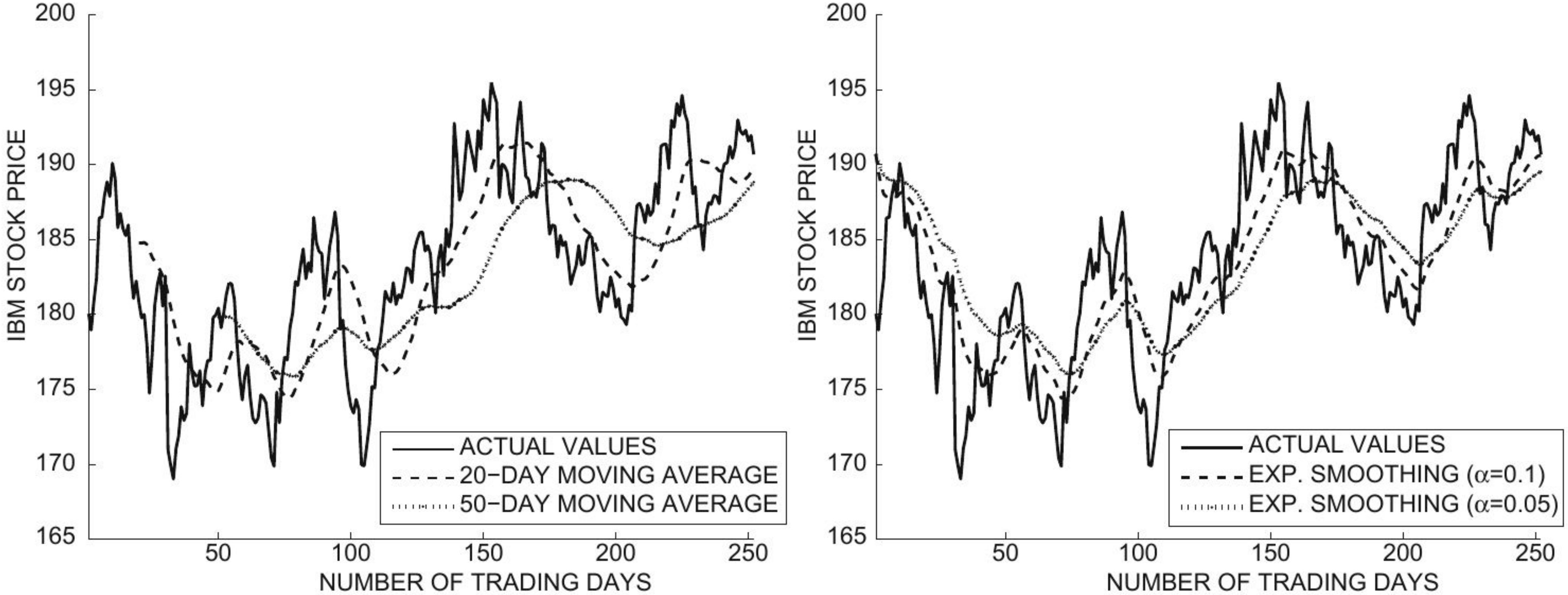
$$y'_i = \alpha \cdot y_i + (1-\alpha) \cdot y'_{i-1}$$

- Recursively substituting



$$y'_i = (1-\alpha)^i \cdot y'_0 + \alpha \sum_{j=1}^{i} y_j \cdot (1-\alpha)^{i-j}$$

Moving average vs exponential smoothing



(a) Moving average smoothing

(b) Exponential smoothing

Exercise: smooth a time series

- Given the following series:

t	1	2	3	4	5	6	7	8	9	10
y(t)	2	4	12	2	1	-2	0	15	3	3
1. y’(t)										
2. y’(t)										

1. Moving average with k=3
2. Exponential average with alpha=0.5

Spreadsheet link:
https://upfbarcelona.padlet.org/sandrabuda1/theory-exercises-tdmvfhddcnvfj5b8

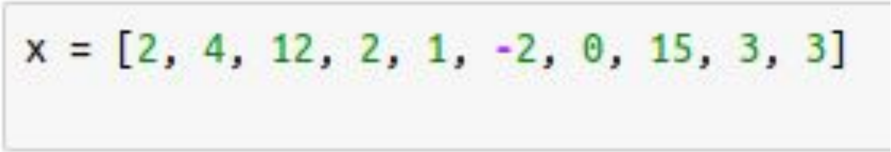
Answer

- Given the following series:

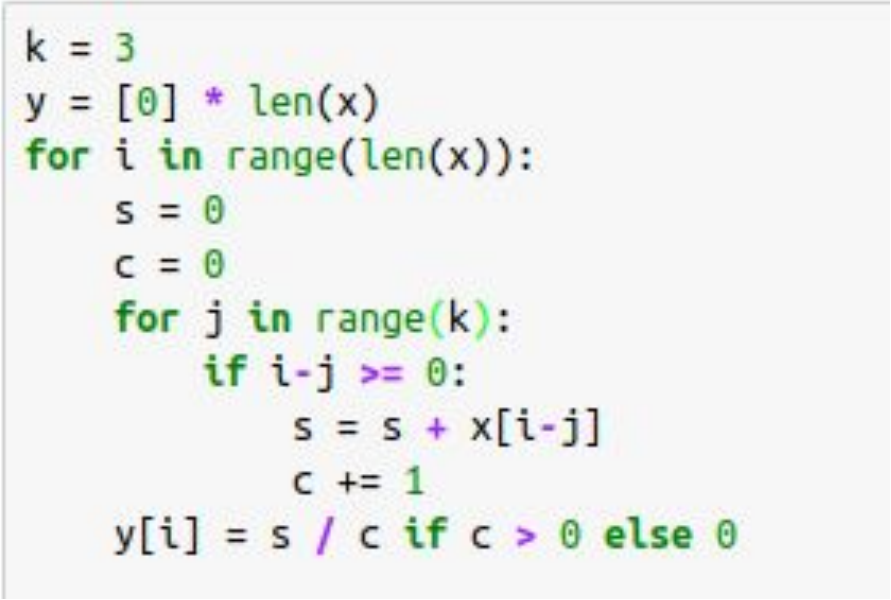
t	1	2	3	4	5	6	7	8	9	10
y_t	2	4	12	2	1	-2	0	15	3	3
y_t'	2	3	6	6	5	0.33	-0.33	4.33	6	7
y_t''	2	3	7.5	4.75	2.88	0.44	0.22	7.61	5.30	4.15

- y_t': moving average with k=3
- y_t'': exponential average with alpha=0.5

Answer (code)



```
x = [2, 4, 12, 2, 1, -2, 0, 15, 3, 3]
```



```
k = 3
y = [0] * len(x)
for i in range(len(x)):
    s = 0
    c = 0
    for j in range(k):
        if i-j >= 0:
            s = s + x[i-j]
            c += 1
    y[i] = s / c if c > 0 else 0
```

Summary

Things to remember

- Series preparation
  - Interpolation
  - Smoothing

Exercises for TT27-TT29

- Data Mining, The Textbook (2015) by Charu Aggarwal
  - Exercises 14.10 → 1-6